RESEARCH ARTICLE

SIMLULATION FOR SEDIMENTATIONASSESSMENTACASESTUDYOF KUNAR RIVERINAFGHANISTAN

Wahidullah Hakim Safi[1], Dr.Vishnu Prasad[2] and Dr. Ruchi Khare[3].
1.   Research Scholar, Maulana Azad National Institute of Technology Bhopal,Bhopal – 462003 India.
2.   Professor, Maulana Azad National Institute of Technology Bhopal,Bhopal – 462003 India.
3.   Asstt. Professor, Maulana Azad National Institute of Technology Bhopal, Bhopal – 462003 India.

Manuscript Info

Abstract

Rivers are easily accessible resources of water for miscellaneous uses but the erosion and sedimentation inrivers are unique and great deal of importance. The analysis of flow and sediment in riverunder different conditions is a base for rivers' behavior and decision making on engineering aspects. Kunar River is an important river of Afghanistan, has considerable interest because of strategic and environmental condition regarding water resources project planning, agriculture, forests, hydropower and industrial scope. This study is carried out to simulate the process of erosion and sedimentation using HEC-RAS model to assess hydraulic parameters and sedimentation processesin 250 Km stretch of Kunar Riverfrom Nari district of Kunar province to Pul-e-Kama of Nangarhar Province. The model was calibrated manually for hydraulic parameters of river flow and then sediment transport model was simulated. The changes in transverse and longitudinal profile, velocity and shear stress variation along the river, mass inflow and outflow, bed level change of river and suspended sediment concentration is studied for the modeled length.The sediment transport from river tributaries and gullies joining the river from two sides of narrow valley isalso assessed.

Introduction:-

Rivers are the major source of water supply for different purposes, the understanding of river conditions, erosion and sedimentation are the main priorities of engineering projects. River is a dynamic system, undergoes continuous changes. The river is also a self-regulatory system asit changesits characteristics in reaction to any change in environment. The environmental changes can either be natural due to climate change and variation of vegetative cover or artificial due to damming, river training, river diversion, sand and gravel mining, channelization, bank protection and bridges and highway constructions.Torestorerivers to equilibrium, they will be adopted to new conditions with changesin bed slope, roughness, bed material size, cross sections shape and meandering pattern. History of each river has dominant influence on the sediment transport rates and the river sediment transport cannotbe estimated without sound knowledge of watershed history and dynamics. The phenomenon of sedimentation including the erosion, sediment transport, sedimentation and consolidation of sediments are most important.

Corresponding Author: -Wahidullah Hakim Safi.
Address: -Research Scholar, M.Tech-Ⅳ seme, Hydropower Engineering Division, Dep of Civil Engineering. Maulana Azad National Institute of Technology Bhopal, India.

Reasonable estimate of sediment transport in alluvial rivers is important in the context of a number of water management issues. Sediment transport is a widely studied topic in which numerous researches have built models for predicting bed material transport in an alluvial river. Information on soil erosion and its effects on water quality at catchment scales are explored by catchment managers. Among several issues resulted from complicated erosion processes, the deposition of sediments are more important especially in rivers having the ability of high sedimentation level (FarhangAzarang et al, [3]).

Sediment accumulation is a problem in many large reservoirs in Afghanistan and worldwide. Available storage of reservoir is decreasing while demand for water is increasing. The reservoirs of Nghlo dam and Kajaki dam which are major water resources project in Afghanistan facing serious problem of reservoir sedimentation. The present study is carried out on sediment transport evaluation and sedimentation capacity of Kunar River with help of HEC-RAS model. Kunar River basin is a main tributary of Kabul Riverbasin that is upper limit is Karakoram of Himalaya Mountains and also carry flow from the southern slopes of Hindu Kush Mountains.

Kabul River basin has94267 Km^2 watershed area with all its sub-basins which are Logar, Panjsheer, Kunar, Center Kabul and Swat. Kabul riverbasin includes 10.6 % area of Indus Riverbasin.Around 40% (1228 tones/km^2/year) of the sediments leaving the Karakoram are glacier-derived.The most of sediment is deposited in the plains, reducing sediment delivery to the Arabian Sea to about 230 tones/km^2/year, leading to high sediment fluxes in the small sub-basins within the Himalaya-Karakoram tectonic zone (David N. Collins 1996, [10]). Kunar Riverbasin as Sub-basin of Kabul River also fed from Karakoram glaciers and has sediment yield around 562.606 tones/Km^2/Yearand hence needsserious consideration of sedimentation problems for planning of any water resources activity on this river.

Since the rate of sediment transport is complex andrelated to various variables such as physiographic characteristics of river basin, bed and flood plain materials of river, stream power and hydraulic characteristics of river thus sediment transport modeling is difficult. Sediment data is uncertain and transport theory is highly sensitive to a lots of physical variables and modeling parameters.

Mathematical modeling of rivers need more physical relationships for sediment transport processes. The fluvial processes are governedby continuity, flow resistance, sediment movements, river bank stability and variation of channel width and are difficult to be presented. Generally width of river changes simultaneously with variation in river bed profile, slope, channel pattern, river channel roughnessetc. All those changes are inter-related which maintains a dynamic state of equilibrium and any imposed factor on the river will be absorbed with combination of above responses (Harinarayan Tiwari et al, [12]).

Hydrologic Engineering Center River Analysis System(HEC-RAS) is a mathematical model for river sediment analysis. HEC-RAS includes mobile boundary and sediment transport capabilities for sediment routing and adopts the channel cross sections in response to sediment dynamics. Sediment transport models require hydraulic parameters, therefore HEC-RAS computes hydraulics before sediment routings or updating cross sections means it keeps flow constant for each flow record, calculate sediment transport on record duration. HEC-RAS 5.0 couples sediment transport computations with either quasi-unsteady hydraulics or unsteady hydraulics.

In this study, steady flow backwater equation for series of flow with associated time are solved using quasi-unsteady model and then unsteady flow model is used to solve the Saint-Venant equation implicitly.

The 47 Km length of Sistan River was studied using HEC-RAS model. The purpose of study was to determine the sediment exposed areas of Sistan River. The transverse and change of longitudinal profile of river, shear stresses changes, and sediment transport capacity were examined(Mahdi Motallebian et al. [1]). The HEC-RAS mode was appliedto Boshar River, a main upstream reach of Khersan River in Karoon catchment which is located in Kohkeloyeh and Boyerahmad Province-Iran, in order to identify the suitable locations for sand and gravel mining along the river reach.(Mohammad Gharesifard et al. [2]). The simulation of erosion and sedimentation processes and also considering cross section geometric changes, prediction of riverand total sediment load of Karun River using HEC-RAS model. The results showed that the Karun River has had sedimentation in its most cross sections while the erosion has been rarely observed. (FarhangAzarang et al. [3])

Study Area:-

Kunar riverbasin is a major tributary of Kabul river basin which upper limit is Karakoram Range of Himalaya Mountains.Himalaya Mountains supplies the world major part of sediment flux to ocean through the five bigger river of south Asia the amount of sediment is estimated 1.73 Giga tones which is 9% of global sediment flux (David N. Collins 1996, [10]). Another side of this watershed is limited with southern slopes of Hindu Kush Mountains.The river catchment include mountains and highlands which is mostly dominated by natural forests.
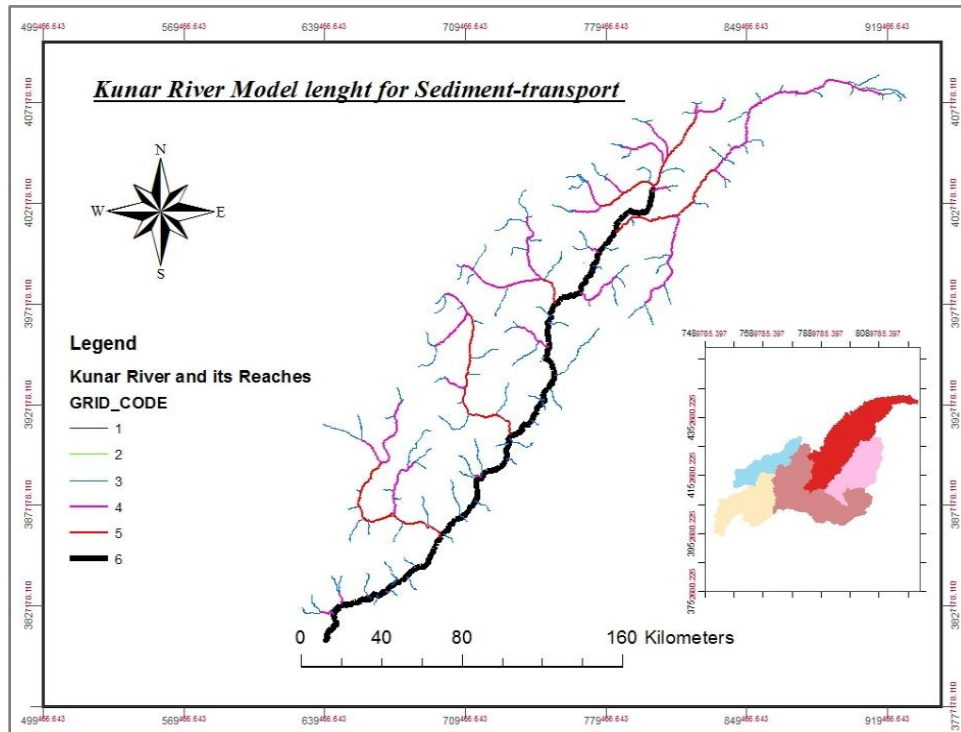

Figure 1:-Modeled area of Kunar River for sediment transport.

The modeled part of Kunar River for sediment assessment shown in Figure 1 has around 250 km length starting from location with Northing 800413.817, Easting 4023940.034 and Altitude 2126 meters and ending at Northing 640141.777, Easting 3809967.814 and Altitude 538 meters. The relief between starting and ending of the riveris 1588 meters and the average slope is determined as 0.00512 for the river channel indicating its scouring.

KunarRiveris divided here into two parts (1) upstream (150 – 250 Km)reach and, (2) downstream (0 – 150 Km)reach as shown in Figure 1. The upstream channel located between mountains with stable bed and banks in this narrow rocky valley. KunarRiverissteep slopedwith highcapacity of sediment transportation. Theriver bed is changed to a fluvial bed in downstream and the river valley become widen with less slopeand low flow velocity, thus river stream has low sediment transport capability. Hence, in the second half part of riverextreme sedimentation occursand Kunar River converts its bed to several channels and hilly patternis looking from sediment accumulations inside the river channels.

Methodology:-

In this work, HEC-RAS 5.0 model which is developed by United States Army Corps of Engineers (USACE) has been used for simulation. The mentioned software is able to simulate the steady flow, gradually varied flow, water quality, and sediment transport. This model has an advanced graphic abilities to display the software outputs.

```
┌─────────────────────┐
│ Sediment transport  │
│       model         │
└─────────────────────┘
```

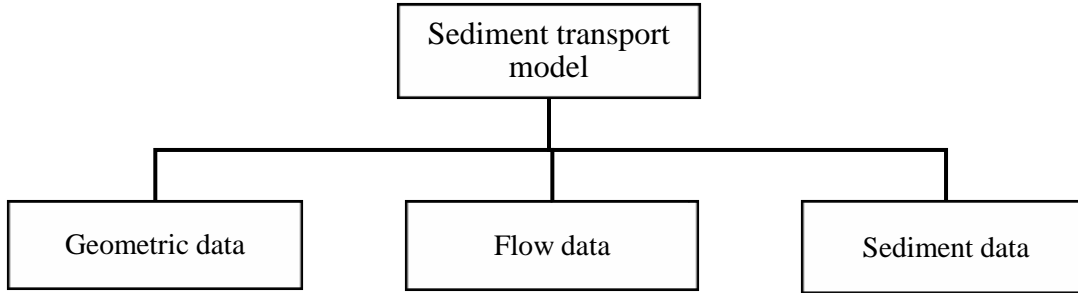| Geometric data | Flow data | Sediment data |

Figure2:-Data required in HEC-RAS model for sediment modeling

The part of this model for sediment load has been developed to simulate one dimensional deposition of sedimentation and erosion of the rivers. The three main inputs data needed for sediment transport computations are shown in Figure 2.

In addition HEC-RAS model need to specify the Transportation Function (TF) based on soil properties of basin. The TF given by Acker-White, Yang and Wilcock has been used in present study and accordingly Sorting Method (SM) and Fall Velocity (FV) is chosen.

Geometric Data:-

For analyzing of a flow problem, geometry is basic input. The geometry is generated using Digital Elevation Model (DEM) in Arc-GIS with help of Geo-RAS. Geo-RAS is an extension of Arc-GIS developed with Hydrologic Engineering Center (HEC) and used to obtain the riveralignment, banks location, flow path and cross section in GIS environment.The geometric data include cross sections, reach lengths and bank locations that is imported to HEC-RAS from ArcGIS.

The Manning's n value should be introduced for each cross section ofriver, banks and flood plainsseparately. In this study, Manning's n is considered 0.031 for riverand 0.02 for flood plains as per guide of United States Geological Survey (USGS Water-Supply Paper 2339 [9]).

Flow Data:-

In the quasi-unsteady flow, a time series of flowdata is requiredto simulatethe sediment model. The flow datais defined as upstream and downstream boundary conditions. In this study, the Gahwardish stations is the upstream boundary and Pul-e-Kama is the downstream boundary of Kunar River. In addition to this, data of Asmar and Kunari tributaries are added to as flow change locations. The flow hydrograph is given in Figure 3.
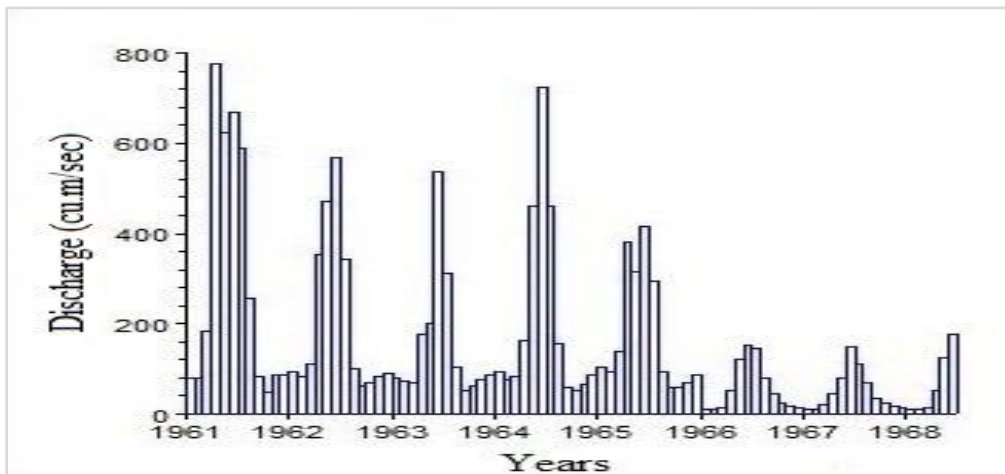

Figure3:- Flow data for Kunar River as flow series in different years.

Sediment Data:-
Sediment data consist ofriver bed gradation, sediment loads (sediment rating curve). The size of sediment particles plays an important role in erosion and sedimentation processes, each cross section should have a gradation curve in the discrete bed. In this study, the cross sections having statistical data of gradation for river reach from upstream to downstream have been used and the interpolation has been used to generate data for cross sections which do not havedata. The rating curve and bed gradation data used in this study are given in Figure 4 and Table 1 respectively.

The rating curve determines the sediment discharge into the river based on the riverdischarge. The obtained flow discharge-sediment load curve for Kunar River is $Q_s = 1.4424 \, Q^{1.7131}$, Qs is suspended sediment load in tone/day and Q is river discharge in m^3/s.
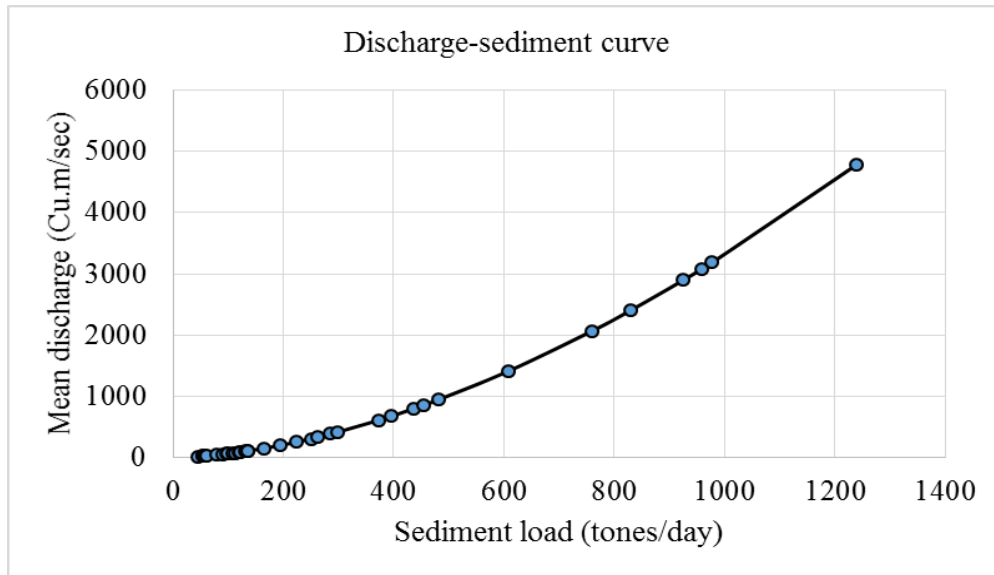

Figure4:-Sediment rating curve for Kunar River.

Table 1:-Bed gradation data

No	Class	Diameter (mm)	Percentage of finer
1	Fine sand (FS)	0.25	0
2	Silty sand (MS)	0.50	8
3	Clay sand (CS)	1.00	24
4	Well graded clay sand (VCS)	2.00	34
5	Very fine gravel (VFG)	4.00	50
6	Fine gravel (FG)	8.00	68
7	Silty gravel (MG)	16	79
8	Clay gravel (CG)	32	85
9	Well graded clay gravel (VCG)	64	95
10	Silty clayey sand with gravel (SC)	128	99
11	Gravelly silty clay with sand (LC)	256	100

Results and Discussions:-
The quasi-unsteady flow (unsteady flow analysis) has been carried forgiven geometricdata and flow data of riverfor sedimentation study in HEC-RAS model. In this software, well known equations are used to determine the total sedimentation load. Predicted change in bed level, maximum change in elevation and other effects are observed which are mentioned in graphical form.

HEC-RAS model for sedimentation give detailed information of erosion/deposition of each cross section, riverinvert and water surface elevation, flow, velocity, shear stresses, mass changes.

The longitudinal bed profile of Kunar River under the study length is shown in Figure 5. The upstream (150 – 250 Km) reach half of river has more slope than the downstream half-length (0 – 150 Km) reach which causes serious erosions in the upstream half-length and sedimentation in the downstream length of river.
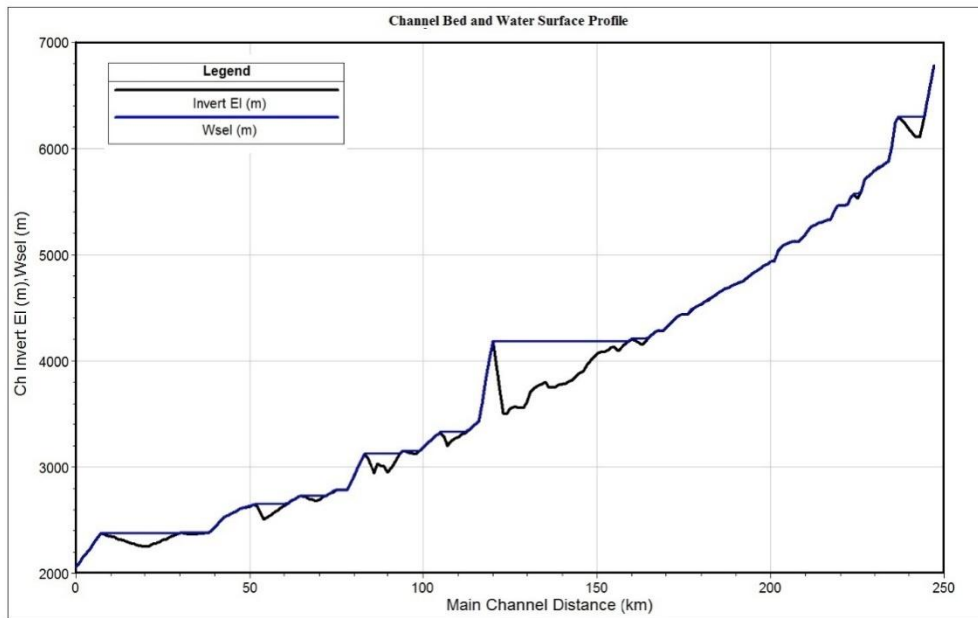

Figure5:-Longitudinal surface water profile along Kunar River

The variation of velocity along length of Kunar River is shown in Figure 6. There is large fluctuations in velocity along the considered reach of channel. The maximum velocity observed is 4.253 m/sec and minimum velocity is very small in some sections where the water depth is more and has a wide surface area.
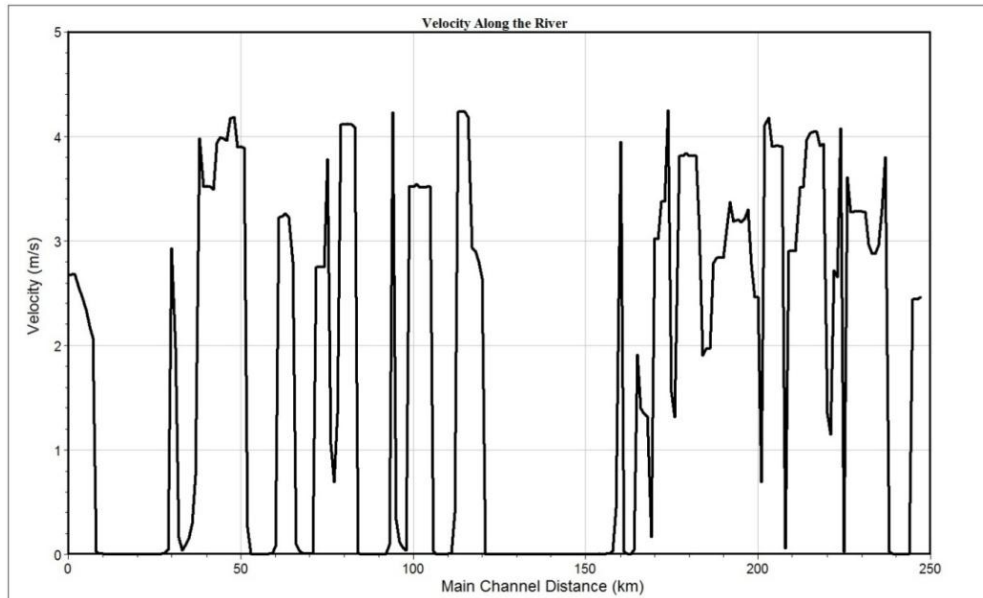

Figure 6:-Velocity distribution along Kunar River

The shear stresses are frictional force which acts against gravity action andthey are directly proportional to specific weight of water, hydraulic radius and slope of the channel. Variation of shear stress given in Figure 7 along the

riverstream indicates that there is almost no shear stress in downstream of river(0 – 150km) reach but in upstream (150 – 250 Km) reach shear stressesare more and fluctuating.

Variation of shear stress along Kunar River may be due to variation of bed slope.   Maximum shear stress is 12.588 Pa while the minimum stress are 0.252 Pa. The maximum shear stress in upstream reach as seen in Figure 7 gives the idea that Kunar River in upstream flows through rocky and narrow valley resulting more friction losses and leading to severe erosion problems.
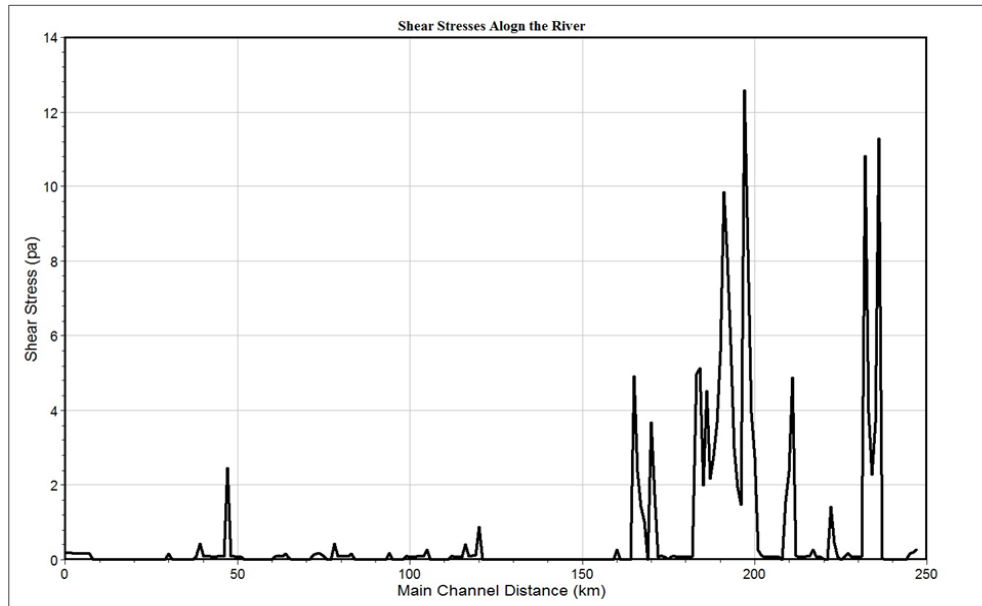

Figure 7:-Shear stress variation along Kunar River

The variation in mass changes in both positive and negative (sedimentation and erosion) direction along Kunar Riverin Figure 8 exhibits intermittent happening of both erosion and deposition processes. In the middle, there is no erosion or desposition in 120 Km to 150km reach. The highest erosion and deposition is observed around 50km reach.

The magnitudes of bed level changes in Kunar river is illustrated in Figure 9.The intermediat occurrences of erosion and sedimentation are observed in all parts of the river.

The maximum depth of erosion in these reaches is about -2.449 mwhich happens in 50 Km and 80 Km river stations and the maximum deposition is about 1.495 m in downstream (30 – 40 Km) reach of river having wide cross section.It is seen that Kunar River experiences sequentially both erosion and desposition.

The sediments are transported by a river in form of dissolved, suspended load, saltation, wash and bed load. Suspended sediments are part of clastic load which move through channel in water column.
,
Mainly silt and sand are kept in suspension by upward flux of turbulences generated at bed of the channel. Maximum sediment concentraion along Kunar river is obtained to be 506,605.9 mg/L. The variation suspended load concentration along Kunar river is given in Figure 10.
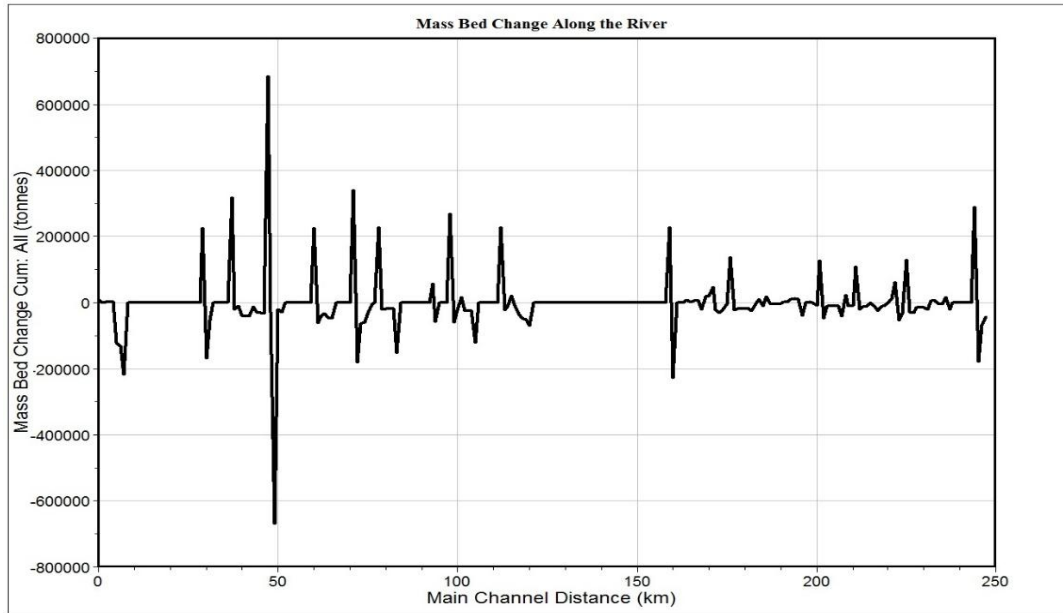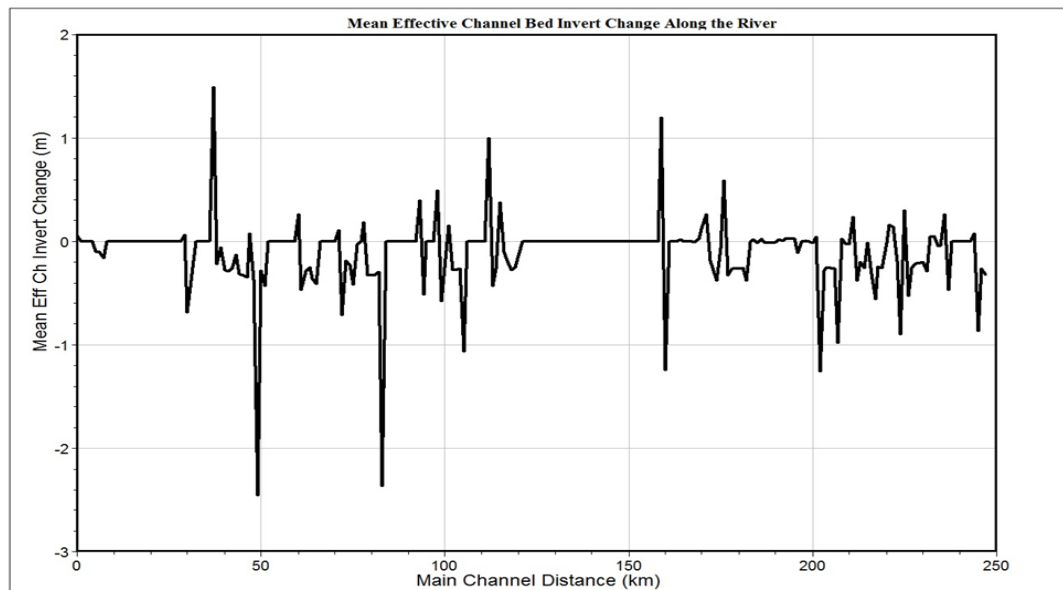
Figure 8:-Mass changes along Kunar River

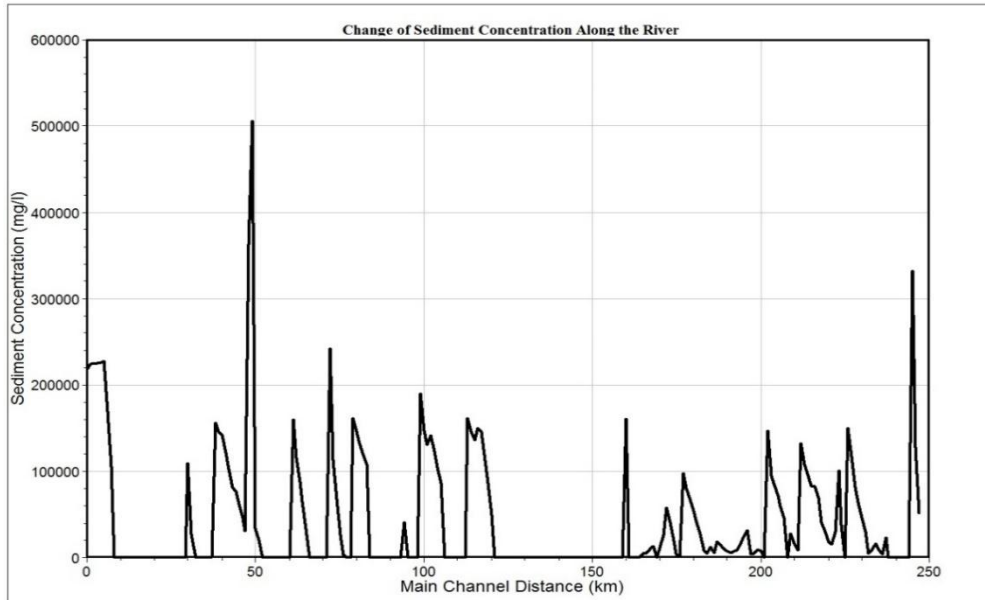**Figure 9:-** Bed level changes along the modeled length of Kunar river.

Figure 10:-Sediment concentration along Kunar River

Kunar riverseems to be a non-aluvial river in upstream because of the riverchannel passes through rocks.There are also pools that are very deep up to 100m which effectively trap sediments. Without three main right tributaries which flow towared Kunar River, 98 temporary streams that can be called gullies join with KunarRiver from right side along the river and 110 gullies join from the left side as an example is shown in Figure 11.

The gullies have very steep slopes which are located at two side of the valley. Some of the gullies have comparatively large watershed area with steep slope that creates flooding during precipitation and transport huge amount of sediments from high mountains of both sides to riveras Kunar River in this part has high ability of transport so flow transports these sediments and Kunar river changes to alluvial nature in downstream part due to huge sedimentation therefore river bedchanges and devided into multi channels as seen in Figure 12.

Figure 11:-Gullies entering to main stream of Kunar river

Figure 12:- Kunar River at downstream reach with multi channeling and sediment hills

Conclusions:-

1. The model was first calibratedmanually using excel sheet for flow hydraulics and then simulating for sediment transport was carried out. The results showed that Kunar river experience erosion in upstream half-length (150 – 250 Km) reachand sedimentation happens in half-length of downstream (0 – 150 Km) reach. There are many pools in upstream length which causing sediments trapping.
2. The maximum erosion is-2.449 m which happens in 50 Km and 80 Km river stationsand might have different reason as high flow velocity or alluvial bed materials. Kunar River has steep slope at upstream half length which can be main reason of erosion processes.
3. The maximum deposition is about 1.495 m in downstream (30 – 40 Km) reach length where Kunar River gets multi channeled feature and sediment hills. One of the main causes of the sedimentation phenomenon can be sudden reduction of river longitudinal slope.
4. It is observed that erosion has been more significant in the areas with steep longitudinal slope and tight transverse sections, while the sedimentation was observed more in the area with flat slope and wide transverse section.
5. Formation of large sand bars due to sedimentation and lack of regular dredging of the river have caused numerous problems including reduction of river capacity in passing flood discharge, severe reduction of Kunar River water quality.
6. The annual sediment yield calculated for Kunar riverbasin is 562.606 tone/km^2/year that is equal to 11.2313 Mm^3/yearwhich is near the sediment yield reported by (David N. Collins 1996, [10]) for rivers of Karakoram region.

References:-

1. Mahdi Motallebian,FarzadHassanpour(2013) "A study of the locus of the erosion and sedimentation in Sistan River using HEC-RAS model"*, International Journal of Scientific & Engineering Research,* Volume 4, Issue 10, October-2013, ISSN 2229-5518
2. Mohammad Gharesifard, Ali Jahedan and BaharMolazem (2012)"Determining the Suitable Sediment extraction Locations of Existing Sand and Gravel Mines on Boshar River in Iran using HEC-RAS Modeling" *International Conference on ScienceEngineering (ICSE6), Paris - August 27-31, 2012*
3. FarhangAzarang, Mahmoud ShafaiBajestan (2015) "Simulating the Erosion and Sedimentation of Karun Alluvial River in the Region of Ahvaz (Southwest Of Iran)" *American Journal of Engineering Research (AJER)*, e-ISSN: 2320-0847, P-ISSN : 2320-0936, Volume-4, Issue-7, PP-233-245 www.ajer.org
4. Amir HamzehHaghiabi and Ehsan Zaredehdasht (2012) "Evaluation of HEC-RAS Ability in Erosion and Sediment Transport Forecasting" *World Applied Sciences Journal*, 17 (11): 1490-1497, 2012 ISSN 1818-4952

5. Stanford Gibson, Chris Nygaard and Paul Sclafani (2010) "Mobile Bed Modeling of the Cowlitz Riverusing HEC-RAS Assessing Flooding Risk and Impact due to System sediment" *Second Joint federal Interagency Conference.* Las Vegas, NV, June 27 – July 1, 2010

6. JafarChapokpour and RasoulDaneshfaraz (2013) "Sedimentary Study of QarranquRiver Using Hec-Ras" *International Research Journal of Applied and Basic Sciences*, ISSN 2251-838X / Vol, 4 (11):3582-3591, 2013 Available online at www.irjabs.com

7. John Shelley, Stanford Gibson and Aaron Williams (20150 "Unsteady Flow and Sediment Modeling in a Large Reservoir using HEC-RAS 5.0" *U.S. Army Corps of Engineers, Hydrologic Engineering Center*.

8. USACE, (2015). HEC-RAS River Analysis System, Version 5.0, "Hydrologic Engineering Center User Manual", U.S. Army Corps of Engineers.

9. GEORGE J. ARCEMENT, JR., and VERNE R. SCHNEIDER(1989) "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" *United States Geological Survey* Water-Supply Paper-2339

10. DAVID N. Collins (1996) "Sediment transport from glaciered basins in the Karakoram mountains" *Erosion and Sediment Yield: Global and Regional Perspectives* (Proceedings of the Exeter Symposium, July 1996). IAHS Publ. no. 236, 1996

11. Khawaja Faran Ali and Dirk H. De Boer (2010) "Spatially distributed erosion and sediment yield modeling in the upper Indus River basin" *WATER RESOURCES RESEARCH*, Vol. 46, W08504, doi:10.1029/2009WR008762, 2010

12. Rahul Agrawal, Regulwar D.G. (2016) "Flood Analysis of Dhudhana River in Upper Godavari Basin Using HEC-RAS" *International Journal of Engineering Research*. ISSN: 2 3 1 9 6890(online), 2347-5013(print), Volume No.5, Issue Special 1 pp: 188-191.